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INVESTIGATION ON ANCHORAGE BOND STRENGTH OF REINFORCING BARS WITH L – BENDS EMBEDDED IN GEOPOLYMER CONCRETE

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ABSTRACT

Geopolymer concrete has been investigated thoroughly in recent times with respect to mechanical strength properties throughout the world. However, that is related to structural behavior of these concretes which needs to be taken up urgently in order to make them acceptable in field applications by practicing engineers. In this regard, studies related to bond strength of reinforcing bars with concrete is of great significant. The attainment of satisfactory performance in bond, when efficiently developed enables the concrete and steel to form composite structure which is the most important aim of reinforcement in RCC structural members. Bond stress in RC members arises due to anchorage of bars in Tension or Compression; anchorage bond problem is merely of determining of the length of embedment required to resist the withdrawal of reinforcing bars. Earlier investigations in GPCs for straight bars had proved that GPCs perform better than conventional concretes in case of bond. Hence, in the present study it deals about the experimental and numerical work relating to the finite element modeling using ANSYS version 15.0 to correlate the anchorage bond strength of L-bends/ 90° bends with that straight bar in geopolymer concrete cubes using Pull out test as per Indian codal provision IS 2770:1967. Standard test specimens with respect to compressive strengths were casted and tensile strength of the rod has been found out for using the data to model in ANSYS version 15.0 and the model developed is validated with experimental data of straight bars and L-bends on geopolymer concrete.

Key words: Geopolymer Concrete, Anchorage Bond, Straight Bars and L-Bend/90° Bend, Pull Out Test.

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1. INTRODUCTION

In any reinforced concrete construction, the transfer of load between steel member and surrounding concrete occurs because of bond stresses. Bond stress is the shearing stress developed at the interface of steel-concrete on account of composite interaction behaviour between the two materials, contributing towards ductility aspect of structural behaviour. The bond enables the steel and concrete to act together without slip at the serviceability limit state and serves to control the crack width and deflection. At ultimate limit state, the strength of laps and anchorages depend on bond. Since the distribution and nature of bond stress is highly complex due to shear lag and effects of cracking and ribs on the bar surface, the codes of practice give importance to development length requirements for transfer of load from steel to concrete which is based upon a uniform nominal bond stress over the length of embedment of the rebar. The bond stress in a reinforced concrete member is developed from the anchorage of bars and change in bar force along its length or due to varying bending moment. The mobilisation of bond must be ensured under loading situations such as tension, compression and flexure. Many studies on conventional concretes (CCs) are available, but, not many investigations on the bond strengths of geopolymer concrete (GPC).

Previously, many of the investigators had a focus on studying reaction mechanisms, mix design, physical and mechanical properties, durability aspects, etc of GPCs **[4-6].** But, studies are also needed on bond between concrete and reinforcement, which is a chief requirement in the reinforced concrete for transfer of force from the concrete to rebar **[7, 8]**. The initial bond strength comes from the weak chemical bond between steel and hardened concrete, but this resistance is broken at low stress. After occurrence of slip, friction contributes to bond **[9]**. In case of ribbed bars, bond is largely contributed due to the mechanical interaction between the ribs on the surface of the bar and the surrounding **[9 -11].** Even the bond mechanics is complex and action is not because only of adhesion of steel with concrete, but mechanical locking is because of projections on the bar. With High Strength Deformed (HYSD) bars the mechanism of reinforcement anchorage is mainly due to reasons such as Adhesion of concrete and steel, Shear strength of concrete and interlocking of ribs with concrete.

The present study on bond strengths of GPC specimens was taken up as per IS: 2770**[2]** and numerical simulation has been done using ANSYS version 15.0**[12]**. The HYSD bars **[3]** had characteristic yield strength of 415 MPa. The test data when compared with provisions of IS: 456-2000**[1]** would create confidence amongst engineers to adopt GPCs for design and construction of RCC structural components.

2. RESEARCH METHODOLOGY

In this project 80 % fly ash and 20 % GGBS is taken as the base material for preparation of geo polymer concrete. Standard cube specimens have been casted to find the compressive strength and Finite Element software ANSYS version 15.0 is used to model the Pull out specimens of Straight bars and L-bends in Geopolymer Concrete. Numerical stress results obtained are validated with experimental stress results.

3. EXPERIMENTAL PROGRAM

3.1. Materials

The precursor materials used in this study were class-F fly ash (FA) and ground granulated blast furnace slag (GGBS). Fly ash was provided by Ennore, thermal Power Plant, India. GGBS was provided by Jindal Steel Plant, Bellary, Karnataka, India. These FA and GGBS were used as main aluminium and silicon sources for synthesizing geopolymer binder. The chemical composition of FA and GGBS analysed using X-ray fluorescence spectroscopy are listed in Table 1.Mechanical properties of Geopolymer concrete has been represented in Table 2 and the tensile test results are tabulated in Table 3.

Table 1 Chemical Composition of FA and GGBS (EDXRF)

Composition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	Na_2O	LOI
FA	47.55	33.45	10.17	2.099	1.65	0.05	0.015	1.1
GGBS	21.58	14.88	1.78	55.25	0.48	2.63	0.015	1.8

Laboratory grade sodium silicate solution (MR SiO_2/Na_2O: 0.86) and NaOH solution (lye contains 50% NaOH concentration) were used to prepare Alkali Activator Solution (AAS) as a combination of sodium silicate solution and lye. Fine aggregate (river sand) with fineness modulus 2.73 and aggregate maximum size of 4.75 mm was used. Similarly coarse aggregate consist of particle sizes consisting of 12.5 mm passing and 10 mm retained were used. The HYSD bars used were generally conforming to IS: 1786[3].

Figure 1 Compressive strength testing by UTM of capacity 40 tonnes

Table 2 Mechanical Properties of Geopolymer Concrete

Mix ID	AAS/Binder Ratio	Compressive strength (N/mm^2)	Modulus of Elasticity(N/mm^2)
GPC80	0.50	39.8	31543

The Tensile strength of 12 mm steel bar is tested in servo control UTM to calculate, Tensile strength, Young's Modulus etc., and the graph obtained through UTM in which X – axis represents Cross Head Travel(in mm) and Y – axis represents the Load(in kN) is shown in Figure 2, from which the Table 3 Properties are determined.

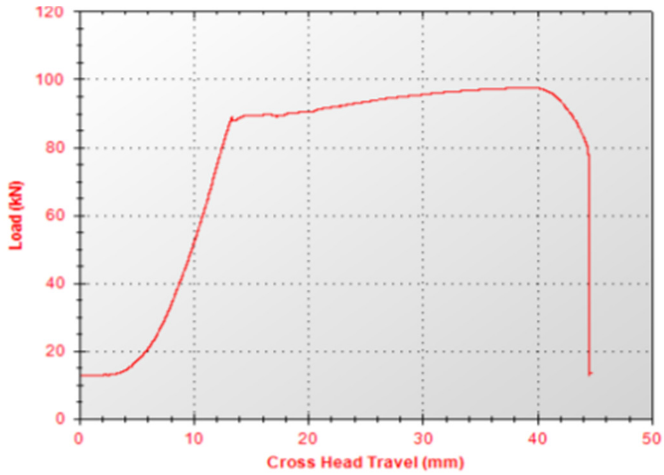
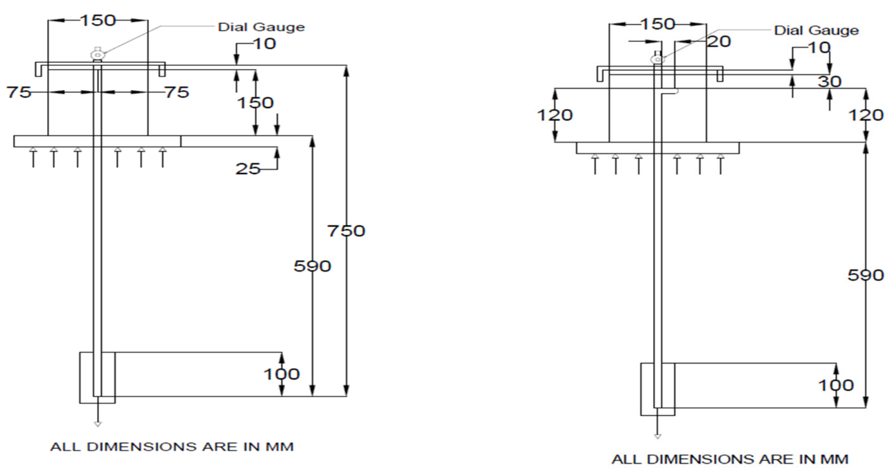


Figure 2 Tensile strength graph obtained through UTM of capacity 100 tonnes

Table 3 Properties of HYSD Bar Used In Experimental Program

Diameter of the bar (mm)	Gauge length (mm)	At Peak point		Extension at Break point (mm)	At Yield point	
		Extension (mm)	Tensile strength (N/mm^2)		Extension (mm)	Yield stress (N/mm^2)
12	450	39.9	861.3	44.82	13.5	775.0

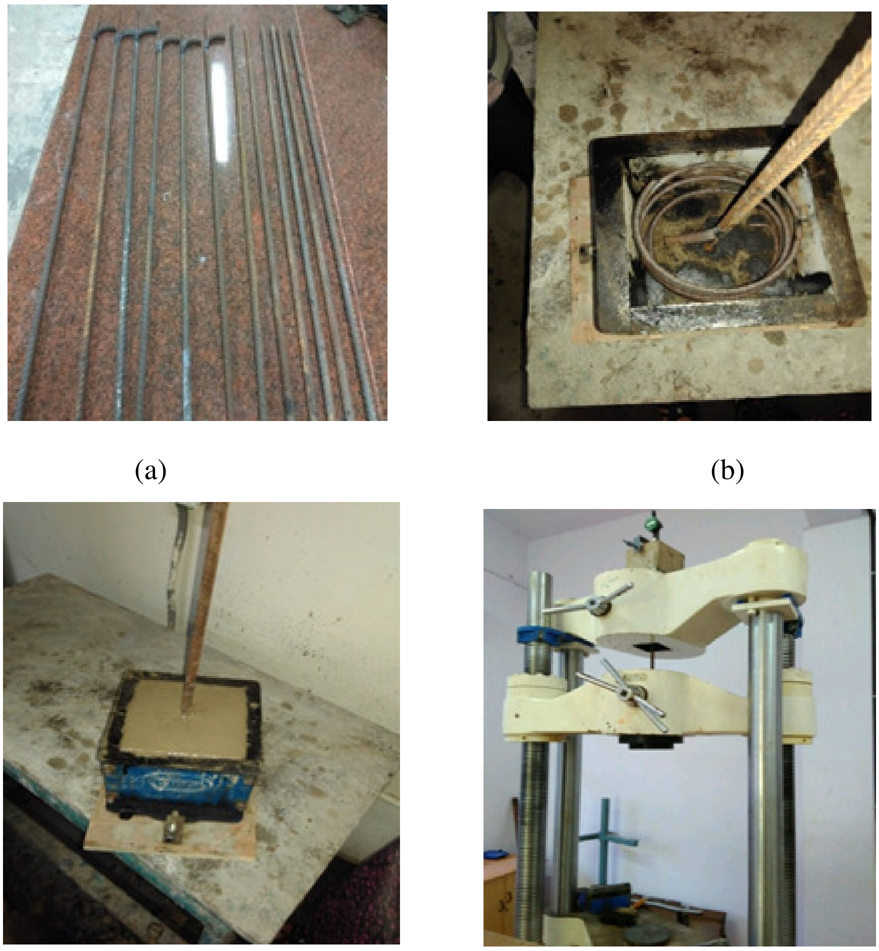
3.2. Geopolymer Concrete Pull Out Test Specimens



(a) (b)

Figure 3 The Schematic Line sketch of test setup for pull out test

Pull out test specimens of cubes with size 150 mm X 150 mm X 150 mm were casted with a helical reinforcement of 6mm diameter plain bar and 12 mm diameter bar is centrally placed and testing carried out in UTM (universal testing machine) of capacity 100 tonnes. Figure 3(a) represents the pull out test setup of straight bar and Figure 3(b) represents the pull out test setup of L – bends.



(a) (b)

(c) (d)

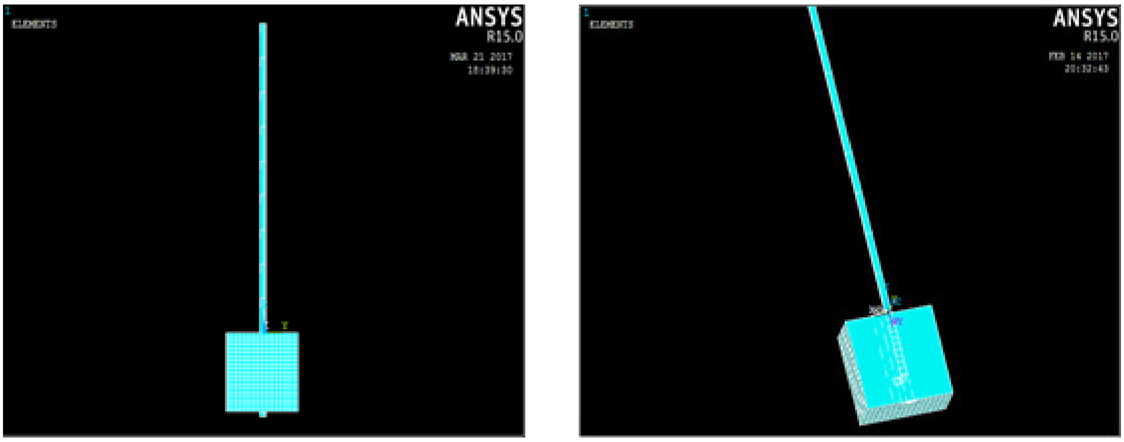
Figure 4 Pull Out Test Specimen Details

Figure 4(a) represents the steel bars of straight bars and L – bend bars (with an attachment of 4mm diameter spokes is done to measure the slip obtaining through anchorage). Figure 4(b) represents the typical mould arrangement for pull out specimen. Figure 4(c) denotes the casted specimen. Figure 4(d) represents typical arrangement of experimental test setup. The results obtained experimentally and numerically are discussed in results and discussions heading.

4. ANALYTICAL STUDY

4.1. Geometry and Modeling

The modeling of finite element analysis of pull out test cube specimen of geopolymer concrete with straight bar is shown in Figure 5(a) and with L - bend is shown in Figure 5(b).



(a) (b)

Figure 5 Numerical model showing Geometry and Meshing of pull out specimens

4.2. Element Types

Solid 65 of eight noded solid brick element with three degrees of freedom at each node and translations in x, y and z directions have been used to model the geopolymer concrete with a Poisson's ratio of 0.3 and density of 0.00207 gm/mm^3. Link 180 (a 3-D spar has been used to model the steel) with a Poisson's ratio of 0.3 and density of 0.00785 gm/mm^3. Coefficient of friction generally have a range of 0.3 to 0.5 and 0.3 is used to create the contact between steel and geopolymer concrete so that both shares the common nodes at the interface.

4.3. Meshing

To obtain satisfactory results from Solid 65 element, a hexagonal mesh was considered and meshing of steel rebar corresponds to meshing of concrete volume is done.

4.4. Loads and Boundary Condition

The boundary conditions for the geometric model are applied at the top surface of the cube for which three directions(x, y and z) are constrained except the nodes adjacent to the steel rebar for which constrained in two directions(x and y) is shown in Figure 6.

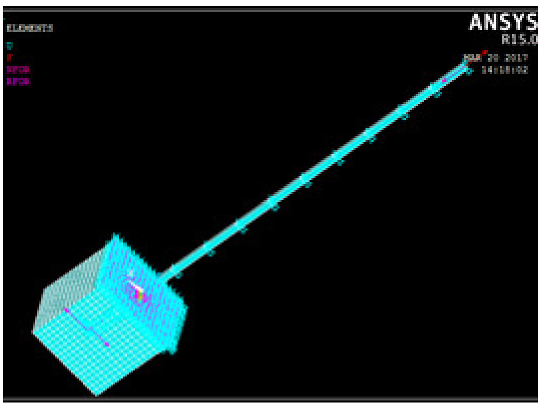


Figure 6 Loads and Boundary conditions for the Pull out Test Specimens

5. RESULTS AND DISCUSSIONS

The results of Pull out test cube specimens with straight bars and L – bends of Geo Polymer Concrete obtained both experimentally and numerically are discussed in the following text. The

average bond stress along the whole anchorage length of steel bar is considered as uniformly distributed as per IS: 2770[1] and it is computed by

$T = P / (\pi * d * l)$

Where, T = Bond stress or bond strength in MPa, P = Load in N, d = diameter of the steel bar in mm, l = embedded length of the steel bar in mm. The mean values of the bond strengths on minimum of three specimens are used.

The Experimental and Numerical design bond stresses as per the IS codes [1] [2] are shown in Table 5 and Table 6 respectively.

Table 4 Experimental Pull out Test results in Geopolymer Concrete

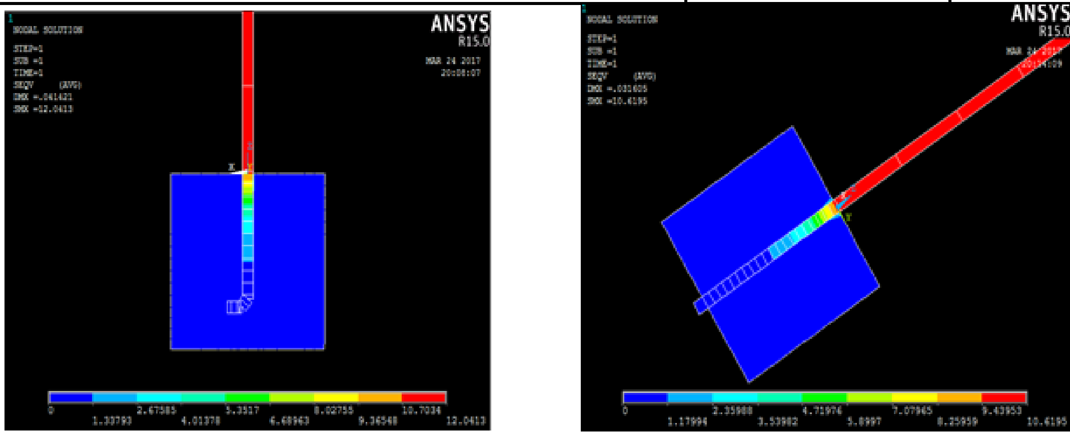
S.NO	DESCRIPTION	Straight	L bend
1	Mix ID	GPC80	GPC80
2	SiO_2/Na_2O	0.86	0.86
3	AAS/ GSM (or) Binder/water	0.5	0.5
4	28 days Compressive strength (f_c) (in MPa)	39.8	39.8
5	Embedded Area ($\pi \times d \times l$) in cm^2	56.5	56.5
6	Slip at peak bond stress , S_{peak} (mm)	0.45	0.45
7	Peak bond stress, T_{peak} (MPa)	9.9	11.2
8	Bond stress at slip of 0.025, $T_{0.025}$ (MPa)	4.5	4.1
9	Bond stress at slip of 0.25, $T_{0.25}$ (MPa)	9.3	10.2
10	Bond stress in IS 456:2000 = $T_{IS\ 456}$ = 0.45sqrt(f_c) (MPa)	2.8	2.8
11	$T_{0.025}/T_{IS456}$	1.6	1.5
12	$T_{peak}/T_{IS\ 456}$	3.5	3.7
13	K= T_{peak}/sqrt(f_c)	1.6	1.8
14	$T_{0.25}$/ sqrt(f_c)	1.5	1.6

The numerical stress results for peak load (obtained experimentally) for Pull out test specimens of straight bars is 10.6 MPa is shown in Figure 7(a). Similarly, Figure 7(b) represents the stress as 12.0 for L – bends.

Table 5 Numerical Pull out Test results in Geopolymer Concrete

S.NO	DESCRIPTION	STRAIGHT	L – BEND
1	Mix ID	-	-
2	SiO_2/Na_2O	-	-
3	AAS/ GSM (or) Binder/water	-	-
4	28 days Compressive strength (f_c) (in MPa)	39.8	39.8
5	Embedded Area ($\pi \times d \times l$) in cm^2	56.5	56.5

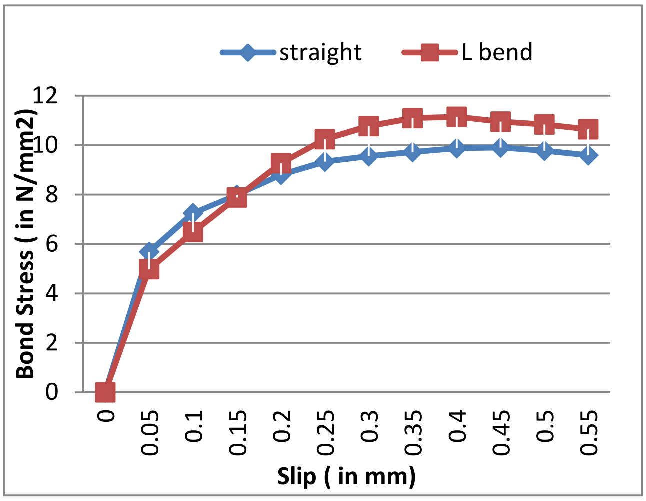
6	Slip at peak bond stress, S_{peak} (mm)	0.45	0.45
7	Peak bond stress, T_{peak} (MPa)	10.6	12.0
8	Bond stress at slip of 0.025, $T_{0.025}$ (MPa)	4.8	4.4
9	Bond stress at slip of 0.25, $T_{0.25}$ (MPa)	9.9	10
10	Bond stress in IS 456:2000 = $T_{IS\ 456} = 0.45\text{sqrt}(f_c)$ (MPa)	2.8	2.8
11	$T_{0.025}/T_{IS456}$	1.7	1.6
12	$T_{peak}/T_{IS\ 456}$	3.8	4.3
13	$K = T_{peak}/\text{sqrt}(f_c)$	1.7	1.9
14	$T_{0.25}/\ \text{sqrt}(f_c)$	1.6	1.6



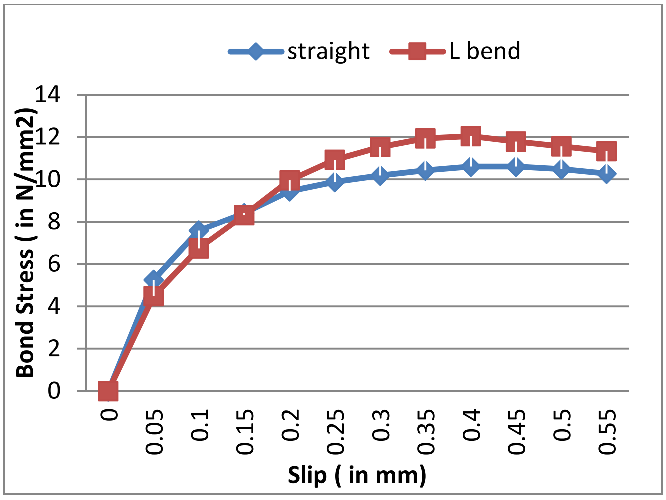
(a) (b)

Figure 7 Numerically obtained Stress results for straight bars and L – bends

Figure 8(a) represents the curve of bond stress (in MPa) versus Slip (in mm) obtained through experiment and Figure 8(b) shows the curve of bond stress (in MPa) versus Slip (in mm) by numerically obtained results.



(a)



(b)

Figure 8 Experimental and Numerical Test Results

Figure 9 represents bond stress versus slip obtained experimentally and numerically for straight and L – bends.

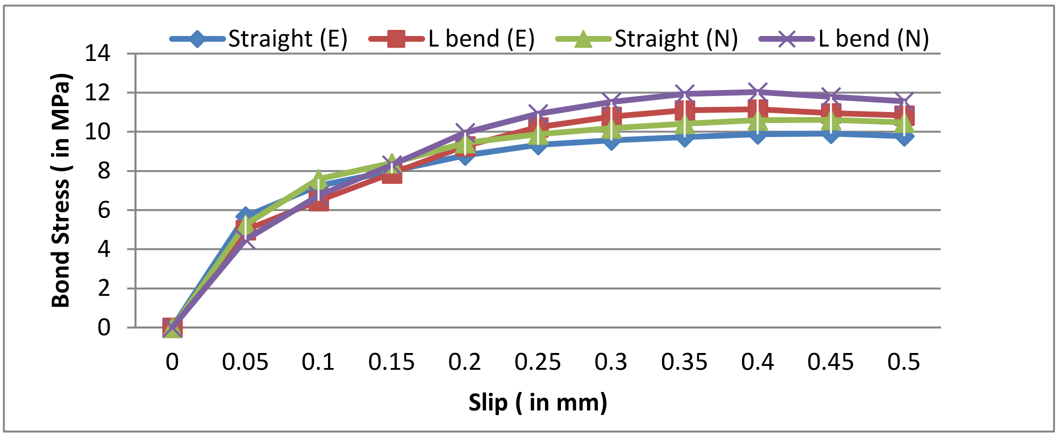


Figure 9 Curve shows Experimental and Numerical results of Bond stress versus slip

6. CONCLUSIONS

Thus, values of bond strengths obtained from the investigation were found to be satisfactory with reference to those specified in IS: 456-2000[1] for the purpose of structural design computations.

- It is observed that Geopolymer concrete of L bends possess 1.1 times the higher bond strengths compared to straight bars.
- The bond stress test values for Straight bars and L bends at slip of 0.025mm were found to be about twice the design bond stress values of IS 456:2000 and about three times more for peak bond stress.
- Percent error for bond stress obtained through experimentally and numerically is 10% which is acceptable.
- Provision of a small L-bend in the reinforcing steel bar for geopolymer concretes (GPCs) enhances the pull out load of the steel bar.

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